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THE INTEGRATION OF SIMNET WITH A THEATER-LEVEL COMBAT MODEL

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The central portion of this paper describes the process by which the major inputs for the TACWAR GC90 attrition subroutines can be addressed by SIMNET output. The GC90 attrition subroutines incorporate recent IDA research on the calculation of attrition and allow an integrated treatment of both point and area fire weapons. While the existing information contained in the SIMNET output is sufficient for most of the TACWAR inputs considered here, there are deficiencies. In particular, this paper notes that for some inputs, further processing of the underlying terrain data base is required and that for coordinated fire, even more detailed processing is required.

This paper also performs an example calculation for one TACWAR input variable - the engagement rate for point fire ground weapons. The procedures to calculate the engagement rates were applied to a collection of SIMNET exercises which varied in size, duration and the degree to which the vehicles were crewed simulators or vehicles operated by the Semi-Automated Forces. The distribution of resulting engagement rates is displayed.

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PREFACE

This paper was prepared under IDA Project 9000-004 as part of the IDA Central Research Program and the IDA Advanced Combat Simulation Center Program. It discusses one approach for using the output from exercises conducted by SIMNET to calculate reasonable values for inputs to one particular theater-level combat simulation, a variant of the Tactical Warfare (TACWAR) model. An example calculation is performed for one TACWAR input -- the engagement rate for a ground weapon. To make this assessment, a collection of SIMNET exercises of varying size and duration were collected and processed.

The authors wish to thank Mr. Tom Radgowsky, Mr. William Riggs, Mr. Paul Monday, Mr. Keith Green and Mr. George Bradford of the BBN Corporation for their generous assistance in helping us generate, collect and process SIMNET exercise data. This work would have been much more difficult without their expertise. Mr. Robert Clover also performed a critical role in this project, spending a considerable amount of time teaching us many of the primary lessons that are necessary for working with SIMNET. Appreciation is also extended to Col. James Walters and Mr. Robert White of the Combined Arms Tactical Training Center, Fort Knox.

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The authors also wish to thank Dr. Anderson and Dr. Alan Rolfe for their valuable comments during their review of this document.

ABSTRACT

This paper explores how data produced by SIMNET may be used to supply inputs to the Tactical Warfare (TACWAR) model, a theater level-combat simulation used by IDA, the Joint Staff and other organizations.

The central portion of this paper describes the process by which the major inputs for the TACWAR GC90 attrition subroutines can be addressed by SIMNET output. The GC90 attrition subroutines incorporate recent IDA research on the calculation of attrition and allow an integrated treatment of both point fire and area fire weapons. While the existing information contained in the SIMNET output is sufficient for most of the TACWAR inputs considered here, there are deficiencies. In particular, this paper notes that for some inputs, further processing of the underlying terrain data base is required and that for coordinated fire, even more detailed processing is required.

This paper also performs an example calculation for one TACWAR input variable -- the engagement rate for point fire ground weapons. The procedures to calculate the engagement rates were applied to a collection of SIMNET exercises which varied in size, duration and the degree to which the vehicles were crewed simulators or vehicles operated by the Semi-Automated Forces. The distribution of resulting engagement rates is displayed.

This paper also shows how simple processing of SIMNET exercise output can isolate both where and when the local battles within a larger battle took place. This capability makes it easier for analysts to better understand how the larger battle comprised perhaps several smaller battles, and how the overall battle varied in location and intensity. This capability is available to any analyst, as it does not make use of the specialized SIMNET hardware and software of the Plan View Display and Stealth Vehicle.

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I. INTRODUCTION

This paper explores how data produced by SIMNET may be used to supply inputs to the Tactical Warfare (TACWAR) model, a theater-level combat simulation used by IDA, the Joint Staff and other organizations.

Although SIMNET was initially developed to serve as a training tool and a combat developments laboratory, each SIMNET exercise produces a large amount of weapon specific effectiveness data. SIMNET thus may be a valuable, flexible source of input data to the usual computer simulations of combat. For theater-level combat simulations, such a new source of input data is particularly appealing. The current procedure makes use of a hierarchy of other models (of lower levels of combat) in order to develop data that are at the appropriate level of aggregation for theater-level assessments. The question investigated by this paper is whether SIMNET can be used directly to develop the inputs for theater-level models.

There would be two immediate benefits of so doing. First, the entire process could be shortened, simplified and thus made easier to audit. Second, the resulting theater-level input data would be based on factors that other data sources may not address, e.g., the actual terrain of the hypothetical conflict, the effects of human operators, and descriptors of individual weapons effectiveness that are derived from battle-like conditions (as compared with test ranges).

There are two reasons why this objective may be feasible for at least one particular theater-level combat simulation, the TACWAR model. First, SIMNET has demonstrated its ability to conduct division-level exercises, as in the March 1990 WAREX exercise. Because TACWAR uses divisions as its fundamental force unit, SIMNET output of division level engagements could, perhaps, directly translate to TACWAR inputs. Second, the SIMNET output data record how each weapon performed at each moment during the battle. One can determine, for example, which weapons engaged which targets, how frequently and at what degree of effectiveness. One recently developed version of TACWAR uses precisely this level of detail as inputs to its attrition equations.

There are practical considerations that may keep SIMNET's full potential in this area from being quickly realized. First, the current version of SIMNET was developed to demonstrate the concept of a distributed interactive simulation. For it to be of use as an analytic adjunct for theater-level combat simulations, it would have to be expanded in a number of ways. Second, too many exercises may be necessary in order to obtain statistically meaningful results from SIMNET. As currently configured, SIMNET is a stochastic simulation in which the results of each exercise reflect the particular tactics, terrain and other random factors of the battle. These points will be discussed further in this paper.

The remainder of this paper will describe the output produced by SIMNET and how this may be transformed to provide values for certain TACWAR inputs. In Chapter II, SIMNET is described in terms of its being a distributed interactive simulation. Chapter III discusses the TACWAR model and indicates the procedure that may be used to integrate SIMNET output with TACWAR inputs. In Chapter IV, an example calculation is carried out for one particular TACWAR input. In conducting these calculations, one not only addresses which elements of the SIMNET exercise are required to facilitate subsequent analyses, but also one is able to measure, by examining a collection of SIMNET exercises, how the calculated measures vary with other descriptors of the exercise such as size and duration of the battle. This paper concludes in Chapter V with several observations concerning the ease with which other types of SIMNET-based analyses may be undertaken.

II. SIMNET: A DISTRIBUTED INTERACTIVE SIMULATION

A. OVERALL PROGRAM

1. Background

Since its inception in 1983, SIMNET has evolved into a unique mechanism for simulating company- and battalion- level combat with men in the loop. SIMNET creates an environment into which manned simulators are placed; their occupants mimic the functions of crews in armored vehicles. Sights and sounds resembling actual combat conditions are created. Images of weapon systems engaging one another are generated. Communications are interrupted and equipment failures occur.

All this is for the benefit of the man in the loop. Of course, "benefit" is the wrong word to use here. "Enlightenment" is more to the point, for the purpose of SIMNET has always been training and combat development. It is a tool for training armor crews and a framework for evaluating the utility of new weapon systems before prototyping.

In the course of performing its functions, SIMNET produces a tremendous amount of data about the various weapon systems being simulated. These include state variables such as position, orientation, and velocity. They also include combat data such as intended targets, munition choices, effects of round impacts, etc. Thus, certain data, such as the empirical probability of kill (Pk) of a particular munition against a given target type, can be determined from SIMNET. While this was never the explicit intended use of the system, its applicability in this arena is the subject of investigation of this chapter.

2. Current Configuration

a. Networks

SIMNET is a distributed simulation. It consists of a long haul network linking together several local area networks. Each local area network (called sites) consists of several simulators attached to the LAN. "Simulator" is taken to mean any computer participating in the distributed simulation.

The SIMNET local area network is the EtherNet. This LAN supports up to 500 computers and carries data at a rate of 10 megabits per second. Certain SIMNET subsystems, such as the Management, Command and Control System (discussed below) are themselves local area networks (in this case, AppleTalk) attached to the EtherNet.

SIMNET's long haul network consists of 56 kilobit (per second transmission rate) or T-1 (1.5 megabit per second rate) lines connecting LANs at Ft. Knox, KY, Ft. Rucker, AL, and Ft. Leavenworth, KS, in addition to satellite links to overseas sites.

b. SIMNET-D and SIMNET-T

Current SIMNET has two variations: SIMNET-D and SIMNET-T. SIMNET-D is the combat development aspect of the system. It is used to test weapon systems before they are built and to develop tactics for employing or defending against proposed or existing systems. SIMNET-T is the training component of SIMNET. It consists of 236 manned simulators connected through local area networks (LANs) and wide area networks (WANs). Specific applications of SIMNET-T include the Armored Officer Advanced Course (AOAC) and Pre-Command Course (PCC) training exercises.

Both SIMNET variations consist of three major components: manned simulators, Semi-Automated Forces (SAFOR), and the Management, Command and Control (MCC) System. Manned simulators are the core of SIMNET and come in several different "flavors." These are the M1 and M2 armored vehicle simulators, the helicopter simulators, and the fixed wing aircraft simulators. Each carries a vision screen that presents the battlefield area from the perspective of an observer at the simulated position of the manned vehicle. Each simulator is equipped with controls that allow the crew to change (simulated) position and orientation or engage other vehicles in combat.

c. Semi-Automated Forces (SAFOR)

An important factor in creating a realistic combat environment is the simulation of an appropriate number of combatants in the battle area. As SIMNET engagements often range from battalion to division level, the number of combatants required can easily exceed the available crews and manned simulators. Semi-Automated Forces, or SAFOR, was developed to resolve this problem.

SAFOR consists of one or more workstations controlling various echelons (e.g., companies or battalions) of unmanned simulated vehicles. These vehicles have no physical counterpart, such as those corresponding to manned simulators; SAFOR vehicles are strictly software fabrications. They are linked to the SIMNET network and issue data packets in a manner indistinguishable from manned vehicles. They can fire munitions and, in turn, be destroyed by opposing weapon systems.

SAFOR workstations are controlled by operators. Each operator inputs commands at a pre-selected level corresponding to the size of unit being controlled. Such commands are entered through the the SAFOR Mission Editor. If desired, the operator can "drop down" the chain of command and assume control of an individual company or a particular vehicle. Current SAFOR is designed for company- and battalion- level units. Future SAFOR will accommodate "Echelon above Corps."

Blue SAFOR vehicles include the M1 Main Battle Tank, the M2 IFV, the 155mm Howitzer, a generic attack helicopter and the A-10 fixed wing aircraft. Red vehicles include the T80 Main Battle Tank, the BMP infantry fighting vehicle, the 152mm 2S3 self-propelled gun, the HIND rotary wing aircraft and the FROGFOOT fixed wing aircraft. Weapon systems modeled in SAFOR include 25mm, 30mm, 120mm and 125mm guns, the SAGGER ATGM, the SPIRAL ATGM, and the 57mm rocket.

The operational characteristics of all SAFOR vehicles and weapon systems can be modified with the Models Editor; thus, new or proposed systems can be simulated. In this sense, SAFOR is "reconfigurable."

d. Management, Command and Control (MCC) System

The Management, Command and Control (MCC) System, like SAFOR, is a mechanism for adding realism to the battlefield environment by modeling items that do not have manned simulators. These include indirect fire, close air support and resupply. The MCC also serves to initiate the simulation by specifying the parameters (battalion supplies, etc.) of the units involved. More precisely, each battalion is served by an MCC system that simulates the following battalion support elements:

Tactical Operations Center (TOC),
Administration and logistics center,
Indirect fire support (howitzers/mortars),
Close air support,
FAAD support,
Supply depots and resupply trucks, and
Maintenance teams.

The MCC system consists of a MASSCOMP 5600 connected to several Apple Macintosh PCs through an AppleTalk network. The MASSCOMP serves as the point of contact with the SIMNET system and the Macintosh PCs are the workstations for the battalion staff. For example, the individual responsible for ammunition and fuel supply will issue commands from the administration and logistics Macintosh console.

The battlemaster, who serves as the exercise coordinator, uses the MCC to initialize the simulation. For example, the grouping of combat vehicles into organizational units, initial locations of vehicles, fuel and ammunition supplies, positions of Tactical Operations Centers (TOCs) and artillery batteries are all specified by the battlemaster through use of the MCC. Other parameters determined by the battlemaster include the number of potential close air support (CAS) sorties, lists of initial CAS targets and lists of initial indirect fire targets.

e. Data Logger

While the manned simulators, SAFOR, and the MCC are the major components of SIMNET simulations, other devices and subsystems play crucial roles in ancillary functions such as data collection and analyses. Some of these record the "action" while the simulation is taking place. Others provide a "viewport" for observers who are not part of the simulations per se, but who have interest in witnessing the developments as they unfold.

The first of these devices is the Data Logger. It captures and records "packets" of data as they are broadcast over the network. (Data packets, or PDUs, contain the fundamental ground truth of the simulation and are explained in some detail in a later section.) This device tags each packet with a time stamp and writes the data to either a tape or a disc. These data files constitute a complete record of the SIMNET exercise. In fact, the exercise can be re-enacted by 'playing back' these data records over the SIMNET network. Such play backs are indistinguishable from real time observations of the actual SIMNET exercise.

f. Plan View Display (PVD)

The second such device is the Plan View Display (PVD). It is a color monitor that displays an aerial view of the battlefield. The user has the option of varying the scale of the display and thus the level of detail of the presented image. The PVD is invaluable for conveying a global picture of the simulated battle.

g. Stealth Vehicle

The last device or subsystem is the Stealth Vehicle. It consists of one or more wide screen view ports, a track ball, and several additional control mechanisms. By manipulating the track ball, the user can observe the SIMNET simulation from any desired perspective. For example, one can maneuver into the turret of a tank and observe the battle from a gunner's point of view. Similarly, by selecting the appropriate option, one can follow the movements of any given vehicle from a position 20 meters behind or above that vehicle.

The Stealth Vehicle cannot be seen by other simulation participants. It is unobtrusive and does not interfere with simulated action.

3. New Directions

The initial contract that guided the five year phase that demonstrated the feasibility of distributed interactive simulation recently ended. As detailed in the next sections, there will be three main programs that will pursue different aspects of the research and implementation of this technology within the user community. The Defense Advanced Research Projects Agency (DARPA) will lead the Advanced Distributed Simulation Technology program comprising what is now known as SIMNET-D and the Semi-Automated Forces (known as SAF or SAFOR). The Program Manager, Training Devices (PM TRADE) will lead the evolution of SIMNET-T's capabilities to develop the Close Combat Tactical Trainer program. In addition, PM TRADE will be responsible for the Aviation Combined Arms Tactical Trainer (AVCATT) program.

B. PROPOSED SYSTEM

1. Combat Development

As new weapon systems are proposed, one often attempts to evaluate their potential well before prototypes are developed. This is not a straightforward task. Generally, evaluation is performed by constructing a model that contains the principal characteristics of the new system and executing the model with enough parametric variations so that system behavior can be quantified. While many theoretical considerations can be taken into account in such a process, it is often difficult to assess human factors associated with the proposed system. To a large extent, such assessments can be made within SIMNET.

To date, the purpose of SIMNET-D has been combat development. After December 1990, Combat Development will come under the Advanced Distributed Simulation Technology (ADST) program. The ADST contractor will maintain the current SIMNET-D facilities while developing new SIMNET software. Semi-Automated Forces (SAFOR) will be rewritten to include echelon-above-Corps sized units (current SAFOR was designed for battalion and brigade levels). Threat tactics will reflect those of proposed forces as well as current forces.

The purpose of ADST will be to further define and develop the technology to create virtual representations of the combined arms battlefield. Emphasis will be placed on enhancing the capabilities of large scale distributed simulation technology. It is expected that ADST will ultimately provide the means for creating a large scale, "force-on-force, free play," virtual battlefield environment.

Toward this end, ADST will enhance and then apply the techniques of "seamless" simulation. This concepts refers to the ability to smoothly integrate an array of disparate computer simulations and actual weapon systems into one electronic network. Participants interact with one another and none is aware of boundaries or interfaces separating the various simulation components. Thus, combat development exercises using the ADST network wiil be able to employ many different types of systems, proposed or current.

2. Training

Traditionally, training has taken place in field exercises. Recently, however, SIMNET-T provided a means through which units could be trained in the use of certain weapon systems under computer generated and controlled conditions.

While SIMNET-T is still in use as a training device, no additional development of the system is planned, according to PM TRADE. As individual simulators fall into disrepair, they will be discarded. Ultimately, SIMNET-T will be replaced by the more extensive Close Combat Tactical Trainer (CCTT) program. CCTT will consist of 1,100 manned ground simulators (M1 and M2) and a new company/battalion- level SAFOR. In addition, helicopter training will be provided through the Aviation Combined Arms Tactical Trainer (AVCATT) program, which will consist of 400 reconfigurable manned helicopter simulators.

CCTT is expected to provide a system to train (up to) battalion-level units in the skills required to effectively perform command and control, combat support, and maneuver functions. It will make use of ADST-developed reconfigurable simulators in order to emulate vehicles such as HMMWV, SP mortars, and others entities not available in SIMNET-T.

C. UTILITY AS AN ANALYTIC TOOL

1. Divergence from Intended Use

Historically , SIMNET was a tool for training and combat development. As stated above, its primary functions were to train armor crews and to evaluate the utility of new or proposed weapon systems. However, the wealth of data produced in SIMNET exercises make it an attractive source of data for analytic purposes. SIMNET output contains human factor data that are either unavailable elsewhere or not as easily quantified in other media. Reaction times, performance degradation, empirical hit or kill probabilities, and various rates and levels of intensity are derivable from SIMNET. These data, once collected and reduced, may serve as input for conventional theater-level models.

The next section outlines some of the data that are recoverable from SIMNET exercises. It also describes the fundamental data unit through which SIMNET conveys information throughout the network. By recovering these units, one can quantify many of the factors that comprise a SIMNET depiction of combat.

2. PDU Information

All SIMNET computations are performed locally, then shared through the underlying network. Information is transmitted in the form of packets or protocol data units (PDUs). These packets contain the fundamental information, such as vehicle position, appearance, or change in status, that is required to make the simulation viable. Computers attached to the network exchange this information via SIMNET's datagram service. This service allows the transfer of up to 1024 bits of data in a single operation (i.e., "datagramming" obviates the need to first establish a connection between the source and destination computers).

A set of rules (protocols) govern the data exchange on any network. SIMNET protocols include three major categories: association, simulation, and data collection. Each PDU belongs to a particular PDU category that determines its structure and the manner in which the PDU is handled. PDUs consist of several component parts called fields. The first is a header field that describes the protocol, type, and size of the PDU. Subsequent fields identify the exercise to which the PDU belongs and carry the particular data the PDU was intended to convey.

The following is a short list of some of the frequently encountered PDUs (subfields, other than the header, are included). It is by no means exhaustive; the intent is to give the analyst some idea of the type of data that might be gleaned from a SIMNET exercise.

1. Vehicle appearance packets: Transmitted between one and fifteen times each second by the processor controlling the vehicle in question. Each packet contains the following data:

Identity:	vehicle ID (a unique code identifying the vehicle) side (Red, Blue, etc.) role or function bumper number
Type:	technical name for vehicle type
Location:	X,Y, and Z coordinates in the SIMNET frame of reference (in meters)
Velocity:	dX/dt, dY/dt, and dZ/dt in meters per second
Orientation:	a 3x3 rotation matrix describing the vehicle's roll, pitch, and cant
Turret orientation and gun elevation: (if applicable)	
Appearance:	dust clouds burning hull other descriptive data

2. Firing packets: These packets are 'broadcast' by the firing vehicle whenever a projectile is launched. They contain:

Firing vehicle ID	
Event ID:	a numerical code that uniquely identifies the firing event
Ammunition type	
Muzzle coordinates:	X,Y, and Z coordinates of muzzle
Projectile velocity:	dX/dt, dY/dt, and dZ/dt of projectile at time of launch

3. **Vehicle impact packets:** Broadcast by the attacking vehicle whenever a projectile fired by that vehicle impacts another vehicle. These packets contain:

Firing vehicle ID	
Event ID:	the number used as an event ID in the firing packet
Target ID	
Ammunition type	
Impact coordinates:	X,Y, and Z coordinates of impact point in SIMNET frame of reference
Impact surface:	hull turret side
Aspect angle	

4. **Ground impact packets:** Transmitted by the firing vehicle when the projectile it fired strikes the ground. These packets contain:

Firer ID	
Event ID:	same number as corresponding FIRE packet
Ammunition type	
Impact coordinates	

5. **Status change packets:** Transmitted by any vehicle that is damaged or repaired. Status change packets contain:

Vehicle ID	
Event ID:	unique identifier of corresponding Firing, Vehicle Impact or other packet
Cause:	reason for status change (e.g., direct fire)
Perpetrator ID:	ID of vehicle causing status change, such as firing or repair vehicle
Affected systems:	new status of all systems damaged or repaired

D. DIS AS A MODEL

1. Input

SIMNET is a simulation. As such, it requires data describing the systems it is modeling. Often these data are performance characteristics of certain vehicles or single shot kill probabilities of particular munitions. Other data include typical threat force tactics and deployment strategies. Typically, these data will be provided by the Ballistics Research Laboratory (BRL) or some other source that has experience with the system in question or, in the case of proposed systems, is responsible for design specifications.

These data are very detailed. Conditional probabilities of kill given hit by direct fire munitions are provided as a function of munition-target pair, aspect angle, and range. For indirect fire munitions, kill probabilities are provided as a function of munition-target pair, aspect angle, range, and type of fuze contained in the munition.

Other input data include items such as force composition of threat units and typical deployment strategies of these entities. Force composition might specify the number of tanks and BMPs in a typical Warsaw Pact tank company or motorized rifle division. Deployment strategy might stipulate the number of forward and rear echelons while conducting defensive or offensive operations. This information increases the level of realism in SIMNET and provides a basis for the development of tactics for ground combat.

2. Combat Between Weapon Systems

SIMNET models combat in a manner consistent with the performance specifications of the weapon systems and munitions involved. Trajectories and flight times of rounds and missiles are calculated from physical considerations whenever they are fired. Random dispersion errors are applied to impact points to account for effects not explicitly modeled. When rounds impact targets, the target vehicle determines the extent of damage and resulting "state change" based upon munition characteristics, impact point, and previous vehicle state. If the result of the impact is determined to be a fire, mobility, or catastrophic kill, then a status change packet is broadcast over the network and appropriate alterations in the vehicle's appearance and performance take place.

SAFOR vehicles have detection and target selection algorithms that govern their fire allocation during engagements. Manned simulators operate according to the judgment of their crews. In the latter case, targets appear on the simulator screens that emulate the scopes and windows of the particular type vehicle represented. Laser ranging is simulated and target selection is made on either independent or coordinated bases.

Combat is "free play." Although a Game Master exists, his function is to initiate the simulation and coordinate certain activities through the MCC system; he is not an umpire. Any actions that take place in the simulation are considered "legal." All results are termed "real."

3. Output

a. Generation and Analysis

The SIMNET PDUs are broadcast over the network according to a fixed set of protocols. These protocols allow SIMNET to meld together simulators across a given LAN, SAFOR vehicles, MCC vehicles and functions, and simulators at remote sites connected through long haul lines.

SIMNET output data are the PDUs described above. They are recorded and assigned a time stamp by the Data Logger. PDUs provide a time history of status of all vehicles in the simulation. They are a record of all rounds fired, their intended targets (in the case of direct fire), their impact points, and their effects. By examining these PDUs, one can reconstruct the entire simulation.

The Data Logger tapes thus become a data source for analyses of issues related to ground combat. The effects of certain munitions used under specific combat conditions can be measured explicitly. Since PDUs are tied to specific vehicles, munitions, and targets, it is possible to determine distributions of rounds by type when confronted by various target arrays. Human effects can be measured because the applicable PDUs carry vehicle identifiers and it is known which vehicles were manned in any simulation.

Although certain kill probabilities are assigned to given rounds in the input stream, one can measure the actual effect of each round through the PDUs. That is, empirical SSPKs (single shot probability of kill) can be constructed by examining the number of rounds fired and the number of kills attributed to the particular type of munition.

Less easily measured effects also can be examined. For example, the impact of terrain on small scale engagements can be observed through repeated trials of similar engagements at different locations. In certain cases, it may be desirable to make repeated runs using SAFOR instead of manned simulators. This would allow the analyst to compile a significant number of outcomes in a shorter period of time than it may take manned simulators to complete the same sequence of trials. Terrain impact and munitions effectiveness would be retained, although human factors would, of course, be lost.

b. Potential Advantages

There are several potential advantages of generating data in this manner. In addition to some of the issues highlighted above, such as human factors and terrain effects, SIMNET allows the analyst to examine the structure of ground combat from a perspective that gives insight into the engagement's component structure. The manner in which large scale engagements are made up of many small battles becomes apparent. The dynamics among the smaller engagements can be examined. Their parameters, such as duration and attrition, can be quantified.

The interplay among the various levels of command comprising a division also can be observed. The impact of order of battle can be measured and effects of variations can be calibrated. If a large scale exercise is being simulated, SIMNET provides an integrated framework for evaluating not only the degree to which the various echelons were engaged in combat, but also the results of each of the local battles. It is this unified view of a large scale engagement that makes SIMNET potentially useful to other theater-level combat simulations.

III. THE TACTICAL WARFARE (TACWAR) MODEL

This section identifies a collection of TACWAR input variables for which SIMNET may be able to provide values. The discussion focuses on the ground combat variables used to assess attrition caused by other ground weapons. For each input variable included in this section, an approach is outlined for how one could use the PDU data or other SIMNET data bases to calculate reasonable values.

A. OVERVIEW OF TACWAR

The Tactical Warfare (TACWAR) Model is a theater-level simulation of combined ground and air combat that may be used to simulate conventional as well as chemical and theater nuclear conflicts. TACWAR is a two-sided, dynamic, deterministic simulation, several versions of which have been developed and applied during the last fifteen years by IDA, the Joint Staff, the Shape Technical Center and other analytic organizations. Studies based on this model have focussed on several potential theaters of conflict, including Central Europe, South West Asia, Korea and, more recently, the Persian Gulf.

In broad terms, the model simulates combat as follows: A stylized theater structure is created for each theater being analyzed by dividing the actual geography among several non-overlapping sectors. Within each sector, opposing forces meet along a separating boundary. While the combat assessments are mostly independent across sectors, there are mechanisms that cause forces to be reallocated if adjoining sectors experience greatly different results.

The combat assessments consider several descriptors of the forces that are engaging in combat, including the weapons actually available to both sides, their respective postures (e.g., attack, defense) and degradations of effectiveness due to shortages in personnel, supplies and other assets. Based on the results of each cycle of the simulation, the boundary line separating the forces in each sector is repositioned to indicate that one side gained territory at the expense of the other side.

The central component of the combat assessment is the calculation of how many weapons were lost, and thus how many weapons remain on each side. The current approach uses a calculated potential for each weapon type to inflict losses on each opposing weapon type. This potential is based on an input weapon score for each system being modeled. One shortcoming of these weapon scores is that they are somewhat arbitrarily determined, i.e., they do not directly reflect the actual munitions used by the weapons that were engaged in combat. Moreover, a given weapon's potential is normally considered static in this framework, whereas in fact it may be highly dynamic, changing with both the available munitions and the available target set.

Recent developments in the mathematical modeling of attrition equations have developed an alternative approach for the assessment of attrition that explicitly considers both the weapons and munitions involved in the combat. These equations more closely tie the combat results to the use of munitions and the capabilities of those that are fired. The first IDA model to contain a version of this newer treatment of ground combat attrition equations is the Theater Land-Air Model (TLAM) of the IDA Defense Planning Program [7]. Subsequent research further developed and implemented this approach in the TACWAR model. It is this latter formulation that is the focus of this paper.

B. NEW ATTRITION STRUCTURES

The attrition structures documented in [1], [2], [3], and [4] collectively concern the situation where there are multiple shooter and target types, where each shooter type may use multiple munition types in each engagement, and where the fire may be point or area fire. Various levels of coordination of the point and area fire also are considered.

This work has been incorporated to varying degrees in both TLAM and TACWAR. It should be noted that while both J-8 and IDA use versions of the TACWAR model to perform combat assessments, the two versions are to be considered distinct from each other. It is the J-8 version of TACWAR that is the subject of this paper.

The new TACWAR code that incorporates the new work is termed GC90. This refers to the Ground Combat subroutine of the model. The documentation of this change to the model, [5], lists new inputs required by the new equations as well as changes in the definitions of existing inputs. Moreover, GC90 addresses the attrition of ground weapons due to attacks by ground weapons, aircraft and surface-to-surface missiles. The chapter concerns itself only with those inputs in [5] dealing with the first category, ground weapon versus ground weapon combat.

One motivation for this work is the need to analyze the relative contributions of specific weapon and munition programs. As there may be specific capabilities that make a proposed system potentially valuable (e.g., the ability of a new munition to defeat advanced threat armor), the combat simulation must be able to effectively differentiate, through distinct input data, the proposed system. A second motivation is that if multiple munition types (for a given weapon type) are being considered, then not only are probabilities of kill at the shooter/munition/target level of resolution needed, but also one must address what happens as the munitions inventories become depleted. The implementation of the new attrition structures requires that new data values must be generated. SIMNET's ability to track each individual resource over the course of the battle may make it a viable source for these new data requirements.

C. TACWAR ATTRITION-RELATED INPUTS THAT MAY BE ADDRESSED BY SIMNET

1. Documentation of GC90 Additions to TACWAR

The main documentation of the GC90 additions to the J-8 version of the TACWAR model is [5]. A document that compares the various approaches for calculation attrition is [4]. In [5], definitions of all those variables that are affected by the new GC90 code are given. These include new TACWAR input variables as well as existing input variables which may acquire slightly modified definitions under certain implementation options. In particular, for all the variables discussed in this section, the full definition is provided in [5]. Only an abbreviated mnemonic definition is provided here.

2. Assumptions

There are several inputs whose purpose is to identify which among several options will be used. For this discussion, it is assumed that following values are selected.

The input INPOON is set equal to 0. This value of INPOON is used to signify that previously defined input arrays from the J-8 version of TACWAR will be used. This will allow, for example, new data for the existing arrays to be developed using SIMNET. The INPOON variable was created for the following reason. For two-sided attrition calculations that are heterogeneous in both weapon and munition types, some inputs are four dimensional. For example, the probability of kill variable could be dimensioned by shooter type, target type, munition type and the side of the shooter. The current version of the J-8 TACWAR subroutine that reads the input data (the INP subroutine) can read only up to three dimensional arrays. Thus, as is done in GC90, certain variables have been partitioned by the side index into three dimensional variables, one for Blue and one for Red. In the future, INPOON might be set to the value 2 if the INP is modified as needed.

The input MVCASO is set to equal 90. With this value, the new attrition options will be used. In this case, the allocations of fire are based on the current opposing forces.

3. List of Variables Considered

The next section will discuss how SIMNET data could be processed to yield values for the following variables:

BFRASM	BFRDSM	BGAREA	BGPKLA
BPKASM	BPKDSM	BSAWA	BSAWD
CBTZSA	CBTZSP	FPKASM	FPKDSM
GWCORA	GWENIA	GWFAEA	GWFAED
GWFAEE	GWFMIA	GWFUMA	GWVUIA
GWVUIB	GWVUIP	RFRASM	RFRDSM
RGAREA	RGPKLA	RPKASM	[illegible]
RSAWA	RSAWD	SIZAIA	SIZNIA

4. Procedures for Manipulating SIMNET Output

a. Variables Relating To Engagement Rates

GWENIA **for ground weapons, the average number of salvos that a shooter can typically make per time period (area fire).**

By examining Indirect Fire PDUs and their corresponding time stamps, one can determine the firing rate for an individual weapon system over a given time span. Theoretically, one can perform this same function for all indirect fire systems in the simulation. The question then becomes: what is the appropriate time period for each system? The TACWAR variable GWENIA is a potential rate over an engagement period. Engagements in SIMNET tend to be sporadic, with levels of activity going from one extreme to the other. Thus it requires some care to develop this input, as Chapter IV demonstrates.

It is noted in addition that while GC90 does not address point fire weapon engagement rates (since these are already included in TACWAR), these data can be addressed by SIMNET in the same manner as for area fire weapons.

b. Variables Related to Allocations of Fire

CBTZSA/CBTZSP **number of area/point fire combat zones in a given sector (indexed by sector).**

TACWAR's theater structure is subdivided into non-overlapping regions called sectors. Sectors in TACWAR loosely correspond to files in chess; they are parallel corridors that extend from the rear area forward to the FEBA and beyond. Often, activities in TACWAR are described on a sector by sector basis.

Within a given sector, certain subregions are often characterized as area fire zones while others are point fire zones. This is the basis for the existence of variables CBTZSA and CBTZSP.

Area fire zones can be determined by the following recipe:

1. Scan data packets for Indirect Fire PDUs.
2. Examine Indirect Fire PDUs and determine the points of impact of the corresponding rounds. Each Indirect Fire PDU contains an impact location data element.
3. By means of a clustering algorithm, define zones of area fire. Typically such an algorithm will be driven by an input tolerance that serves as an upper bound for the spatial separation of rounds within the same zone.

Point fire zones might be defined in a similar fashion. Instead of Indirect Fire PDUs, however, one must examine the Fire PDUs and determine the firer and target locations for point fire engagements. These pairs of points can be used to define "chords" for the point fire zones. Again, an input tolerance can be used to define clusters or zones.

c. Variables Relating to Probabilities of Kill

BGAREA/RGAREA **for Blue/Red ground weapons using area fire, the size of the potentially lethal area.**

BGPKLA/RGPKLA **for Blue/Red ground weapons using area fire, the probability of kill within the lethal area.**

Indirect fire missions are conducted in SIMNET. These can be MCC or SAFOR functions. In either case, a lookup table determines the probability that a given vehicle within a given distance of the detonation was damaged or destroyed by the detonating round. Tabular data include range, aspect angle, fuze type, and vehicle type.

By analyzing indirect fire results in SIMNET, one could determine the following statistics:

1. the frequency of catastrophic or mobility kills by range cell for a given munition-target vehicle pair,
2. the frequency of indirect fire missions, and
3. the empirical distribution of catastrophic or mobility kills due to indirect fire missions.

The third statistic might serve as a basis for area fire parameters such as BGAREA, RGAREA, BGPKLA, and RGPKLA: it describes the actual effect of an artillery or mortar round. Errors associated with aiming, incorrectly reported target location, communications breakdown, and various other factors are contained in the empirical distribution.

Indirect fire PDUs provide the data necessary to construct the empirical distribution. They contain the time, location, and shooter ID for one or more detonations. A description of the projectile and fuze also are included. Thus the analyst has accurate information regarding the characteristics of the indirect fire munitions. By comparing these data with effectiveness data (i.e., the status change packets) and vehicle appearance packets, one can construct the distribution in question.

BPKASM/RPKASM **the probability that Blue/Red weapon system kills Red/Blue weapon system when firing a particular munition in attack posture.**

BPKDSM/RPKDSM **the probability that Blue/Red weapon system kills Red/Blue weapon system when firing a particular munition in defensive posture.**

Fire PDUs contain a data field that identifies the intended target. An event identifier also is included in the PDU. By comparing this event identifier with its corresponding member in Status Change PDUs, one can determine if a given vehicle was damaged or destroyed by a given round.

Thus an algorithm for determining these variables might have this form:

1. For each vehicle engaging a live target, tabulate the intended target and the event ID from the Fire PDUs.
2. Record the number of rounds of a particular type fired at the target.

3. Record the number of vehicles of the same type as the intended target that are destroyed in the simulation by rounds of the type recorded in "2", fired by weapon systems of the type tabulated in "1."
4. Divide the number in "3" by the number in "2."

One characteristic of this algorithm is the fact that no PDUs carry information relative to attack or defense postures. Thus there is no immediate way of differentiating between the two. Some form of time history must be kept off-line in order to correlate offensive/defensive posture with engagement outcomes.

Note that GWPKLP is a multiple of BPK*SM or RPK*SM.

FPKASM/FPKDSM **factor used to modify kill probabilities on attack or defense, depending upon battle posture.**

Future SIMNET is expected to have a dynamic terrain capability. Tanks and other ground weapon systems will be able to "dig in" during engagements. In the future, therefore, it may be possible to conduct tests that quantify the degree to which Pks (probabilities of kill) vary, depending upon the "battle posture." The current version of SIMNET does not have this capability.

GWCORA **for ground weapons, the size of the area used to coordinate area fire.**

First it must be established that SIMNET coordinates area fire. In the MCC system, "fire for effect" missions produce a barrage of rounds that impact the ground in a pattern that reflects the position of guns in the firing battery. Thus, in the sense of [2], there is coordination among the shooters within a battery. By examining the location field and appropriate time stamp associated with each Indirect Fire PDU, one can determine the zones of coordinated area fire. By further restricting the examination to those PDUs generated by a single weapon system, one determines the impact points that define coordination areas. The area in question might be that of the convex hull of these points or the area of the union of circles of a given radius centered at these points. By averaging this result over all like weapon systems on one side of the engagement, one produces an approximation for GWCORA.

In [5], it is recommended that the options for coordinated fire not be used without further research. It may be a fruitful area of investigation, therefore, to use SIMNET to attempt to develop data for this and related variables. In this manner, the implementation of the coordinated fire options in the model may be tested against an externally generated data set.

GWFAEA **for ground weapons, the fractions that inflict attrition according to the various equations for area fire.**

This parameter is very difficult to determine from SIMNET data. It refers to the different ways in which area fire is coordinated. Loosely speaking, these are: uncoordinated (independent), coordinated among weapons, coordinated among weapons and munitions. No parameters or PDUs carry this information directly; it would have to be inferred from the simulation output. For example, Indirect Fire PDUs do carry impact point and munitions data. It may be possible to draw some inferences based on these data and the accompanying time stamps. In order to accomplish this, fairly sophisticated statistical procedures would have to be employed. It would, perhaps, be more efficient to elicit this information from doctrine.

GWFAED/GWFAEE **for ground weapons, the fractions that inflict attrition according to the various equations for point fire on defense/offense.**

Generally speaking, these variables present the same set of difficulties as their corresponding members for area fire. However, there are more data in the case of point fire that allow an analyst to make inferences regarding coordination. Specifically, Fire PDUs contain a target field and a munitions-type field. By comparing the Firing PDUs belonging to a particular engagement, one could determine if fire were allocated over all feasible targets or, perhaps, directed at one particular target at a time. Conceivably, one could also make a similar determination about the coordination of munitions among similar weapon systems, etc.

d. Variables Relating to Munitions Use

GWFMIA/GWFUMA **for ground weapons, the average fraction of area salvos that are typically fired using munitions of each type.**

Indirect Fire PDUs contain an Indirect Fire Variant data element that, in turn, contains information regarding the type of projectile (and fuze) employed. By tabulating the various types of munitions contained in these PDUs, one can determine the fraction of area fire salvos using a particular projectile type.

BFRASM/RFRASM	**allocation of attacking weapon systems using particular munitions against defending weapon systems.**
BFRDSM/RFRDSM	**allocation of defending weapon systems using particular munitions against attacking weapon systems.**

These data are derivable from Fire PDUs in a straightforward manner. As in earlier cases, it may be necessary to preserve some form of time history of events in order to distinguish offensive actions from defensive ones.

BSAWA/BSAWD	**allocation of attacking weapon systems as a function of posture against defending weapon systems.**
RSAWA/RSAWD	**allocation of defending weapon systems as a function of posture against attacking weapon systems.**

As in earlier cases, these data may be derivable from Fire PDUs. Since posture is an integral part of these variables, however, it may be more appropriate to attempt their derivation under a future SIMNET that models dynamic terrain.

e. Variables Relating to Areas of Vulnerability

GWVUIA	**ground weapon vulnerability input for area fire.**
GWVUIP	**ground weapon vulnerability input for point fire.**
GWVUIB	**ground weapon vulnerability input for both point and area fire.**

The fraction of ground forces that are vulnerable to area fire but not vulnerable to point fire can be determined as a function of time in SIMNET. To determine this fraction, it is necessary to know the locations of the various artillery and mortar batteries and all vehicle locations. Simple range calculations will indicate which vehicles are vulnerable to battery fire.

To determine which of these vehicles are also vulnerable to point fire, certain intervisibility and additional range calculations must be performed. While the latter are straightforward, intervisibility calculations may involve special post-processing software. In particular, the INTERVIS program, which is part of the ADST software suite developed by BBN, calculates intervisibility among vehicles at each instant of time. By applying software like INTERVIS, one could determine a time sequence of vehicles vulnerable to point fire and, a fortiori, a sequence of vehicles vulnerable only to area fire.

GWVUIA, GWVUIP, and GWVUIB are functions of which side is on the attack in a particular sector. As such, a time history of dispositions must be kept for the simulation in question. Again, this follows because no SIMNET PDUs carry these data explicitly. If it is not possible to maintain such a history, then a time averaged approximation might be used for GWVUIA, GWVUIP and GWVUIB, independent of disposition.

SIZAIA **size of target area input for area fire.**

When SIMNET artillery batteries "fire for effect," the pattern of ground bursts reflects the distribution of the battery guns. The size of these impact regions will, of course, depend on the number of batteries and the number of guns per battery. As discussed above, the Indirect Fire PDUs give explicit indication of the area and shapes of these impact regions.

SIZNIA **size or area needed to operate weapons for area fire.**

Spatial distributions of indirect fire weapons can be determined directly from Appearance PDUs, as these entities contain the location of the weapon system in question. Once locations and numbers of weapons are known, a routine calculation yields SIZNIA.

5. Three Technical Considerations

It must be noted that the current version on SIMNET contains a very limited set of resource types and types of interactions. For example, the tanks fire only two types of munitions, the TOW vehicle fires one type of TOW missile, and artillery fires one type of round. There is no simulation of surface-to-surface missiles, or the effect on the close-in battle of interdiction missions. The other air and air defense assets are similarly limited in the numbers of distinct types that SIMNET can represent. The values that one may derive today from SIMNET may be influenced by these limitations and voids on the simulated battlefield. As SIMNET evolves, these limitations may be lessened.

Second, not all of the required aspects of a SIMNET engagement are in readily accessible form. The PDU information can be processed in an automated manner, but information that is terrain specific cannot. Information such as which targets can be seen would require precise processing of both the physical locations of the vehicles (and their alignments) as well as the topography of the terrain (as given in the terrain data base).

The third point concerns the statistical properties of the data generated by SIMNET exercises. For both manned vehicles and SAFOR vehicles, the course of a SIMNET exercise is stochastic. It may require either repeated trials or other estimating techniques to obtain TACWAR input values that satisfy certain confidence levels. Because SIMNET has to date been designed to operate in real time, repeated trials of large scale engagements are not easily conducted. For example, the study team performed a series of parametric variations of a company-level engagement involving only SAFOR units during a two day period at Fort Knox. The battles were on average 12 minutes long; but only four trials of six different cases were generated during a two day period.

D. OTHER CATEGORIES OF TACWAR INPUT DATA THAT MAY BE ADDRESSED BY SIMNET

1. Consumption of Supplies

The performance of each SIMNET vehicle is determined at each moment by the status of several factors, all of which are available to subsequent analyses. These factors include the terrain on which the vehicle is located, the crew behavior if it is a manned vehicle, the stock of munitions associated with the vehicle, and the quantities of petroleum, oil and other necessary consumables required to operate the vehicle.

2. Munitions Consumption Due to Combat Loss of the Vehicle

There are at least two primary sources of munitions consumption during an actual battle. The first is the use of munitions as they are used to engage other targets. The second is the loss of those munitions that were on a vehicle at the time that vehicle was destroyed. For analyses of the overall impact of advanced munitions, this potential source of munitions consumption may be especially important, due to the high cost and relative scarcity of the advanced rounds.

SIMNET records at frequent time intervals many status descriptors of each vehicle, thus one can determine the remaining munitions load on each vehicle at the time that it suffers a firepower or mobility kill. In the latter case, one must further determine if the vehicle was eventually recovered.

The GC90 additions to TACWAR do not address the dynamic simulation of munitions stockpiles. While each ground weapon may in effect carry and use multiple munition types during a model time period (i.e., cycle), the model does not automatically determine that the stocks of a particular munition type eventually were exhausted.

A more detailed treatment of dynamically simulated munitions stockpiles may be found in the TLAM model. In addition, TLAM uses input variables to estimate the consumption of munitions due to the loss of ground weapons. For some cases, this source of loss may be significant. In one scenario, out of 35,000 advanced anti-tank munitions consumed (by a particular Blue weapon type), only 25,000 were actually fired at enemy targets. The remainder were estimated to be lost as these Blue weapons were themselves killed.

3. Fratricide

SIMNET vehicles can and do inflict mobility kills on other vehicles on their own side. It is not uncommon during a SIMNET exercise to see vehicles running into each other as they maneuver in close proximity. This effect may be even more pronounced among SAFOR vehicles, as they must rely on computer algorithms to effect accident avoidance. Such algorithms are complex and remain the focus of current research.

The event of a vehicle's being damaged in this fashion is recorded as any other event that causes damage to a vehicle. The extent of the damage and the agent (i.e., munition or vehicle and vehicle ID) are recorded in the Status Change PDU.

4. Rates at Which Vehicles Become Unready

The performance of a vehicle is also determined by its repair state. The total vehicle repair status considers a number of critical subsystems, each of which can be degraded over time by randomly occurring failures (based on input mean time between failures data) or instances of direct damage by some agent. If the degradation is severe, the vehicle may require maintenance before it returns to a ready status.

IV. AN EXAMPLE CALCULATION OF A WEAPON'S ENGAGEMENT RATE

A. INTRODUCTION

This chapter demonstrates for one TACWAR input variable -- the engagement rate for point fire ground weapons -- how one could actually process SIMNET output to obtain reasonable estimates of this input's values. This exercise highlights two issues. First, it indicates the care with which the moment-by-moment events of the actual SIMNET battle must be analyzed. Because TACWAR requires a potential engagement rate, it is not sufficient to calculate from a SIMNET exercise the overall observed engagement rate. Second, by developing estimates of this one input using SIMNET battles of varying size, one can begin to test the validity of some of the modeling concepts that form the basis of the mathematical attrition equations. In general, the new attrition equations are homogeneous in the number of shooters and targets. A loose interpretation of this point is that as engagements of varying sizes are considered, the equations would yield results proportional to the size of the engagement. While the equations use as inputs the numbers of shooters and the numbers of targets, each shooter is ascribed a fixed inherent engagement rate for the time period being simulated. What is shown in this section is one distribution of engagement rates calculated from a collection of SIMNET exercises that varied in duration, size and intensity.

B. THE ENGAGEMENT RATE INPUT FOR TACWAR

The TACWAR input variable of interest here is the engagement rate for direct fire ground weapons, ERTA [6]. This value refers to the potential number of engagements that a weapon of a given type can make per model time period. In TACWAR, the model time period for some scenarios is twelve hours.

It is important to differentiate the potential rate from other measures of how many engagements each vehicle experienced in a two-sided dynamic exchange. A simple example is now given to illustrate this point.

Assume that there are 10 weapons on each of two sides, that each weapon on both sides is identical and that each weapon has the inherent capability to make 10 engagements per hour. If these weapons engaged each other on a battlefield, one might possibly determine that by the end of the hour, each side made 50 engagements (since weapons were being lost over time). While the average number of engagements per vehicle is 5, this value reflects the results of the two-sided engagement. This is precisely what TACWAR was designed to calculate. One cannot, therefore, input the number 5 into TACWAR; if anything, one should input the number 10. The question to ask, therefore, is how to process the minute-by-minute events of a SIMNET battle in order to arrive back at the original number 10?

A reasonable approach is to assume that as long as a vehicle is alive, it is engaging targets at some rate that is inherent to the tactical situation of the battle. The objective is to determine the total potential number of engagements for each weapon type. First, one determines the total number of engagements, by weapon type. Second, one keeps track of how long each weapon remained alive (which may be for the duration of the battle). Finally, one multiplies the duration of the battle by the per minute rate that each weapon experiences while alive

In the above hypothetical example, if each vehicle engages at a constant rate of one engagement every 6 minutes (for as long as it is alive), then the above algorithm would yield the value 10, no matter what rate of attrition is experienced (except in extreme cases).

C. APPROACH

A series of SIMNET exercise tapes were obtained by this study; they were derived from four types of exercises. First, there are two segments taken from the WAREX 3/90 exercise. Each of these segments occurs within the context of the two day division-level WAREX 3/90 battle. Next, there is one example of a Pre-Command Course (PCC) exercise. (Several of these PCC exercise tapes were obtained, but due to SIMNET software incompatibility, only one could be processed for this effort.) Third are two Armored Officer Advanced Course (AOAC) exercises. These are company-level exercises comprised entirely of manned simulators. Fourth are 18 company-level exercises that played SAFOR versus SAFOR.

For each exercise, the original data recorded by the Data Logger were further processed by the staff at the Fort Knox facility. Of the several files thus created for each exercise, only the following three were used in this calculation.

1. The ID file -- giving the ID numbers of each vehicle. The vehicle ID and vehicle type (e.g., M1, M2, T72, BMP) are used in conjunction with the other files.
2. The Impact file -- listing each impact event, including those that were misses. Each time instance of a vehicle firing a munition (e.g., a machine gun burst, a tank round, a TOW missile) is represented by a record in this file.
3. The XY file -- giving the location of each vehicle (at five second intervals) for the duration of the battle.

The first two files are part of what is referred to as the Standard Output. The Standard Output represents an extensive collection of different programs that may be used to process any SIMNET exercise.

For the third file, a special program had to be developed by the BBN staff. This program processed the vehicle appearance PDUs, which give the basic positional data.

Taken together, the above three files allow a time series to be developed for each vehicle. One can determine the vehicle's position, whether the vehicle is engaging a particular target and when the vehicle is damaged or killed.

D. ASSUMPTIONS USED BY THIS CALCULATION

Each SIMNET exercise tape reflects all the activity that was occurring during the exercise. In particular, for large battles, data are being recorded by the Data Logger that corresponds to perhaps several distinct, simultaneous battles. It was assumed for this calculation that each exercise represented a single localized battle. This assumption will be reexamined below for one particular exercise.

The battle start and end time were defined as the time of the first and last engagement, respectively. Only those vehicles that either were firing munitions or were struck by munitions were considered to be in a position to engage targets. If in position, the total time that such a vehicle was alive was counted towards the total number of alive vehicle minutes for the type in question.

SIMNET records rounds and missiles fired, not engagements. An engagement may be thought of as a period of continuous attention (and rounds) visited by one shooter upon one target (for point fire weapons). For the present purpose, it was assumed that if one minute passed after the firing of a round before the next round was fired (or the vehicle was killed or the exercise ended), then the engagement ended.

E. TABULAR AND GRAPHICAL RESULTS

Of the 24 SIMNET exercises that were fully processed, 22 were subsequently analyzed. They are listed in Table 1 with an abbreviated exercise title. The AOAC exercises were performed on July 13, 1990 in two sessions, the morning and the afternoon (as indicated in the titles). The PCC exercise was performed in April 1989. This series was executed entirely on SIMNET-T. Due to the Army's assuming responsibility for this component of SIMNET in April of this year, software incompatibilities developed between the programs that generated the PDU information during the exercise and the programs that read the resulting files for later analyses. Only one of the four PCC exercise tapes was able to be processed for this study.

At the end of March 1990, a large (upwards of 1000 vehicles) several day division-level exercise was conducted, named WAREX 3/90. During this exercise, personnel at Fort Knox recorded on an 8mm tape drive certain intervals of the battle (because the IDA Rosslyn SIMNET facility can read tapes only in this format). The two segments analyzed here are named WAREX 5 and WAREX 7.

The remaining exercises listed in Table 1 were generated by the study team with the assistance of BBN personnel during a two day period in July. The original purpose was to play SAFOR units against SAFOR units for company-sized battles. In the course this experiment, repeated trials of several different cases were executed. Each different exercise and trial is noted in the titles of Table 1 (e.g., SAF B1 was the first trial of what was called the base case; SAF B2 was the second trial of this base case, etc.).

The other cases varied for the Red forces the effectiveness of their munitions, the marksmanship levels, the movement rules and the unit composition.

Table 1 lists some of the statistics for these exercises. All of these values resulted from the procedure developed to calculate the engagement rate. The number of vehicles refers to the sum of the M1, M2, T72 and BMP vehicles that participated in the battle (they either fired munitions or were the target of munitions). The duration of the battle was defined as the elapsed time between the first and last engagement. The per vehicle minute engagement rate was calculated from the total number of engagements for that vehicle type divided by the total number of alive vehicle minutes experienced by that vehicle type.

There are eight figures that display these data and other calculations as distributions with respect to the number of vehicles and the duration of the battle, as given in Table 1.

Figures 1 through 4 depict the data from the last four columns of Table 1. These values give the inherent rate at which vehicles of each type can engage.

Figures 5 through 8, by contrast, reflect the total engagement potential for each vehicle type. These data are derived by multiplying, for each exercise, the engagement rate per vehicle minute by the duration of the battle.

Table 1. Data Derived from a Collection of SIMNET Exercises

Exercise Title	No. of Vehicles	Duration (Min.)	Per Vehicle Minute Engagement Rate For:			
			M1	M2	T72	BMP
AOAC-AM	14	39.7	.0730	--	--	.7132
AOAC-PM	20	36.0	.0770	.0866	.0914	.0000
PCC	133	71.9	.0870	1198	.1921	.0833
WAREX 5	82	52.2	.0541	.0453	.0413	.0741
WAREX 7	31	11.5	.1967	.1889	.6621	.2424
SAF B1	27	7.2	.2311	.3080	.1602	.2497
SAF B2	26	3.8	.3641	.3681	.8432	.4196
SAF C1	42	6.6	.2950	.4129	.3154	.2471
SAF C2	15	1.2	3.0000	.8745	2.0000	2.2091
SAF D1	26	4.4	.3112	.4161	.6567	.2891
SAF D2	25	3.2	.6957	.5040	.3760	.4428
SAF D3	21	0.9	3.6773	2.8675	3.0000	2.7933
SAF D4	26	2.3	.7951	.8602	.8650	.6789
SAF MK1	18	1.1	3.0000	1.1772	1.000	2.0576
SAF MK2	23	2.1	8704	.7738	.7395	.6790
SAF MK3	15	0.8	2.0000	1.8647	1.0000	1.9647
SAF MV1	20	4.3	.5475	--	.5596	--
SAF MV3	20	3.0	.4548	--	.5546	--
SAF MV4	20	2.6	.7723	--	.7251	--
SAF T1	29	3.8	.3758	.4835	.4353	.4239
SAF T2	33	6.8	.2647	.2984	.2020	.2384
SAF T3	32	7.9	.3514	.3113	.2172	.2030

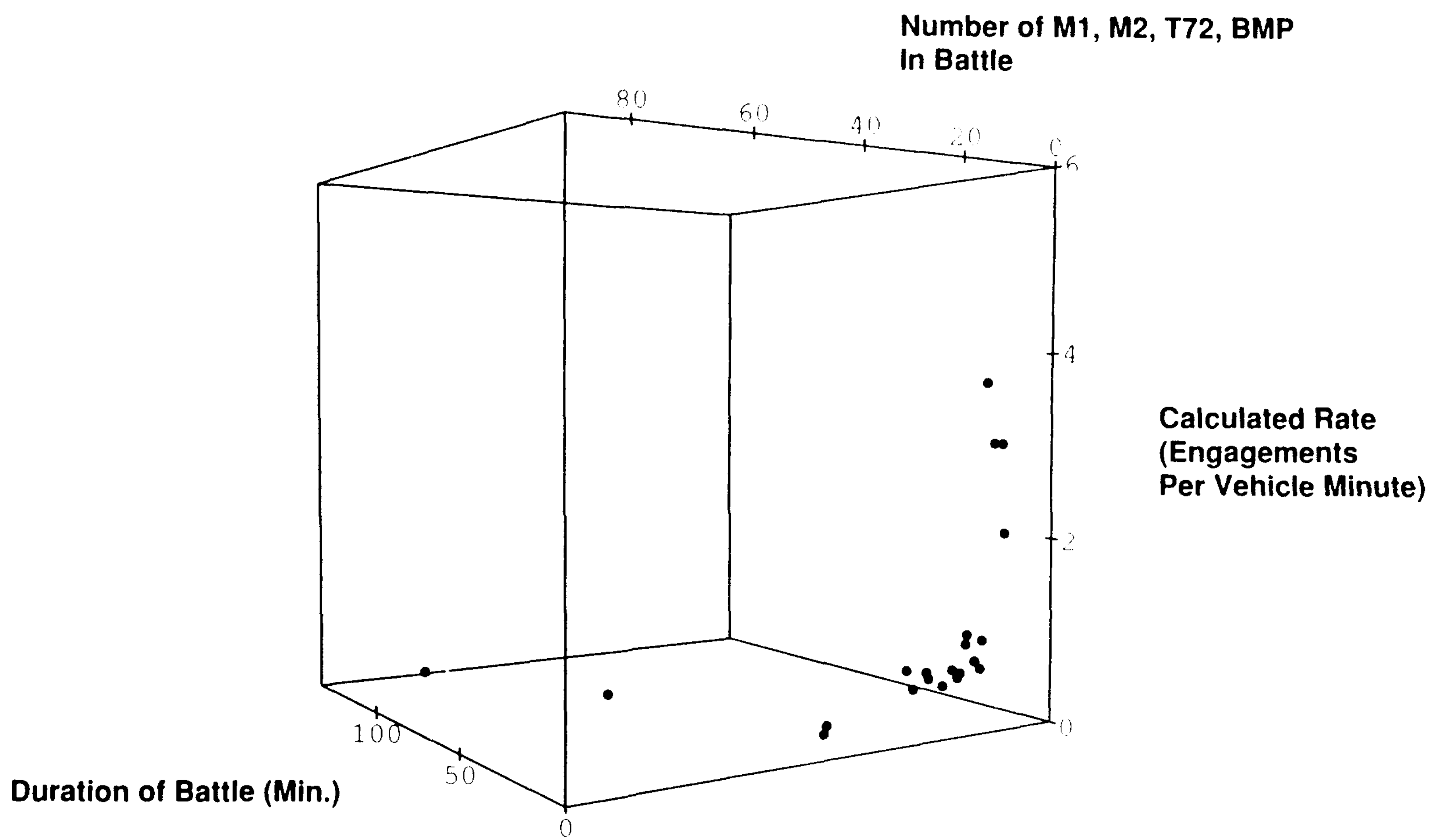


Figure 1. Number of Engagements Per Vehicle Minute for M1

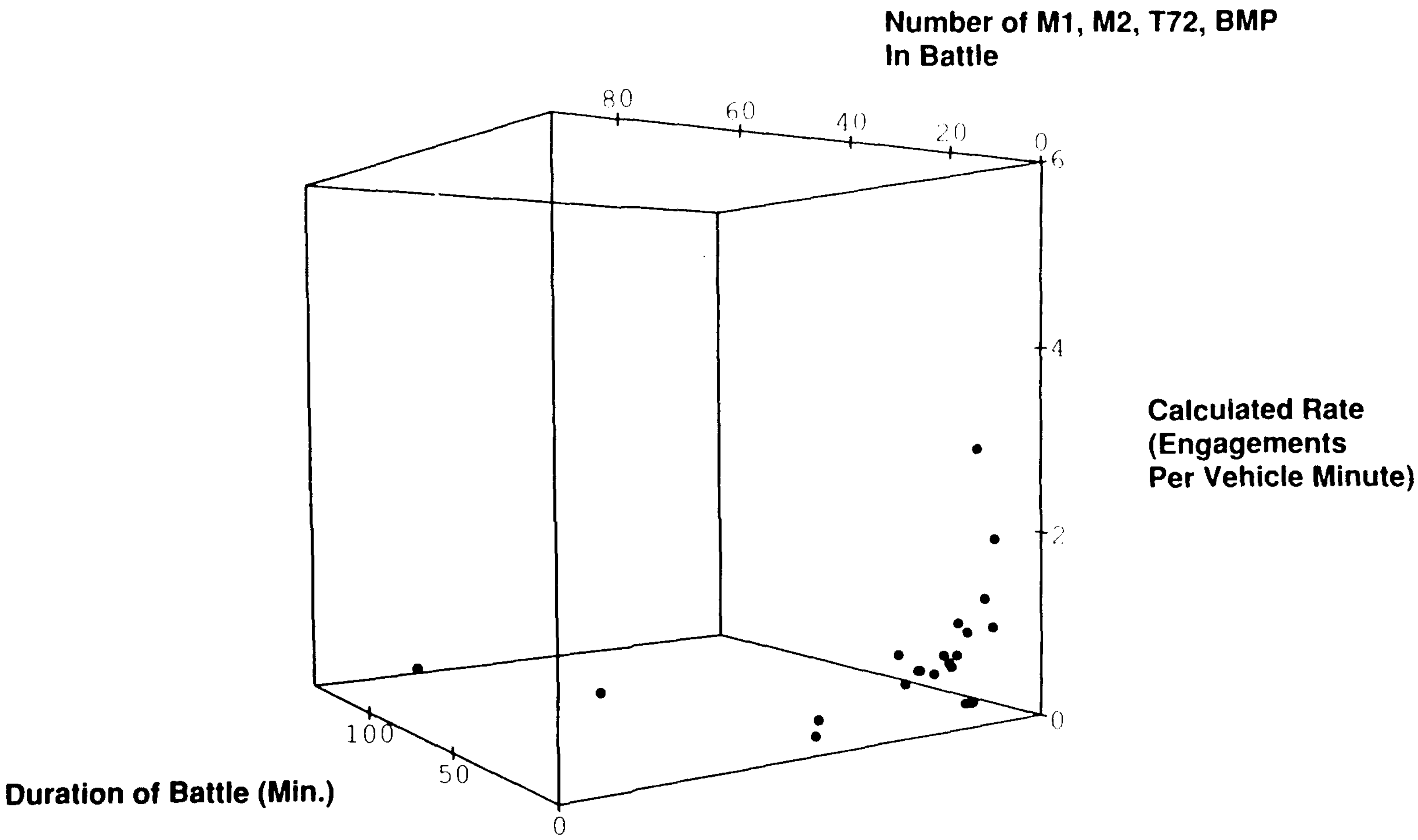


Figure 2. Number of Engagements Per Vehicle Minute for M2

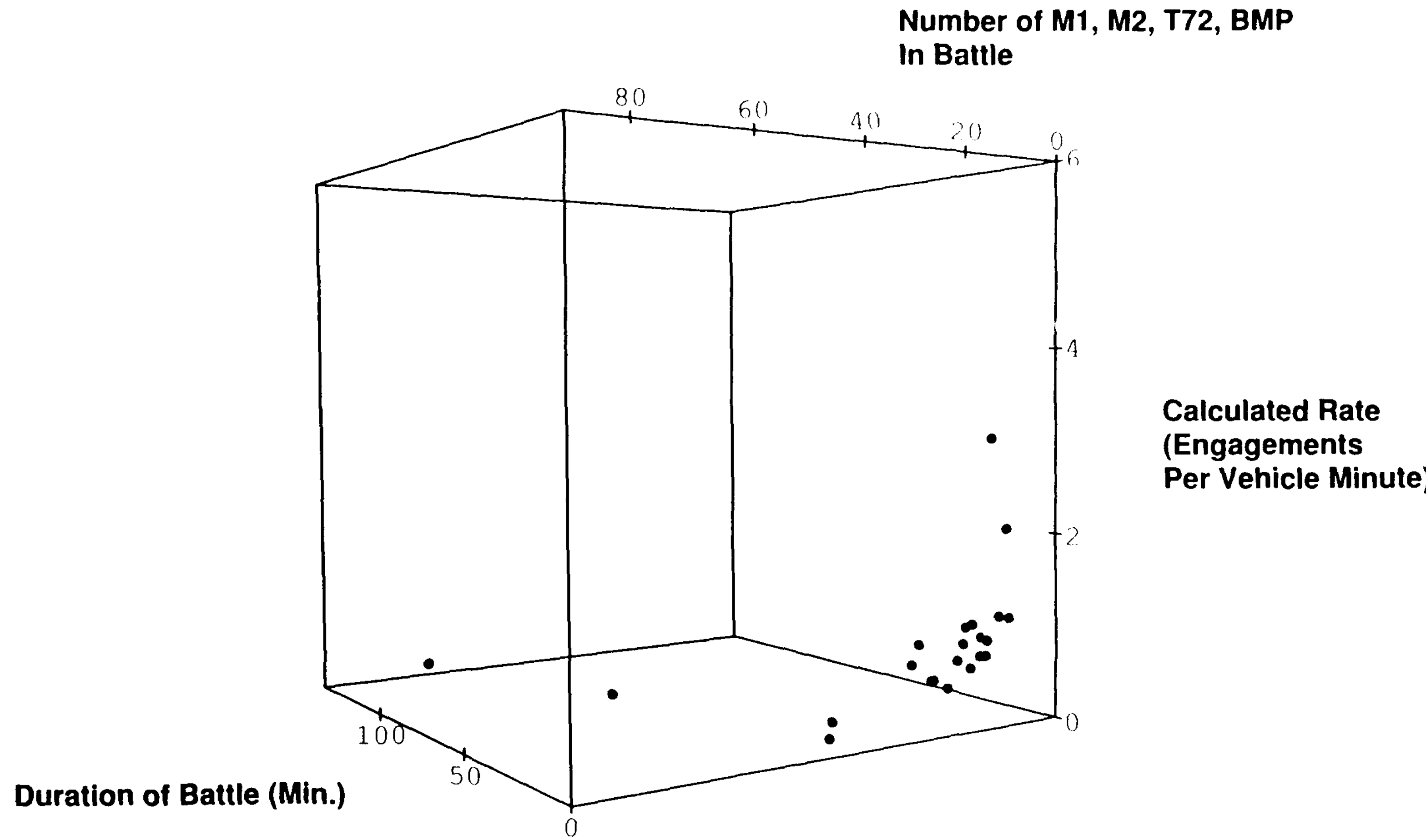


Figure 3. Number of Engagements Per Vehicle Minute for T72

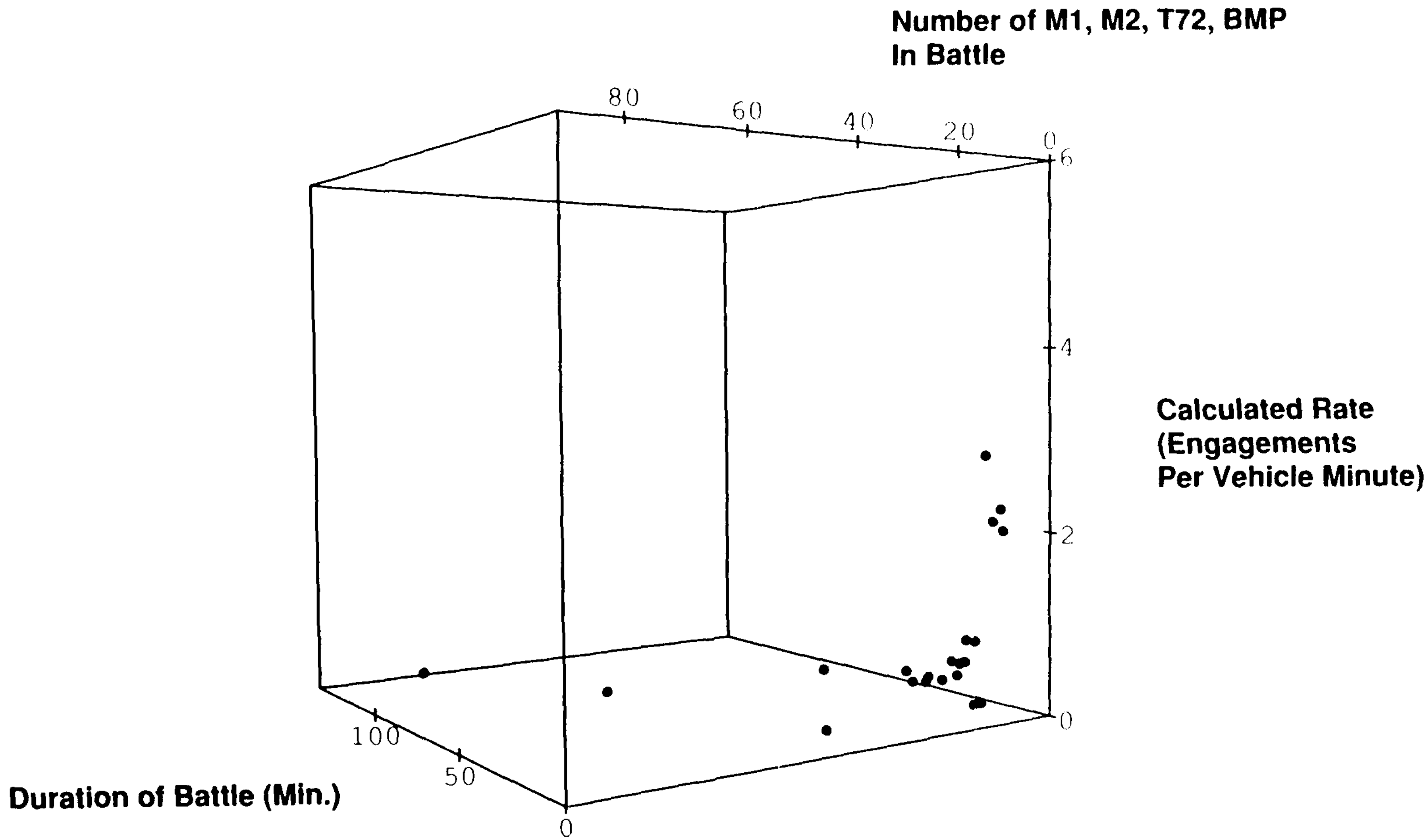


Figure 4. Number of Engagements Per Vehicle Minute for BMP

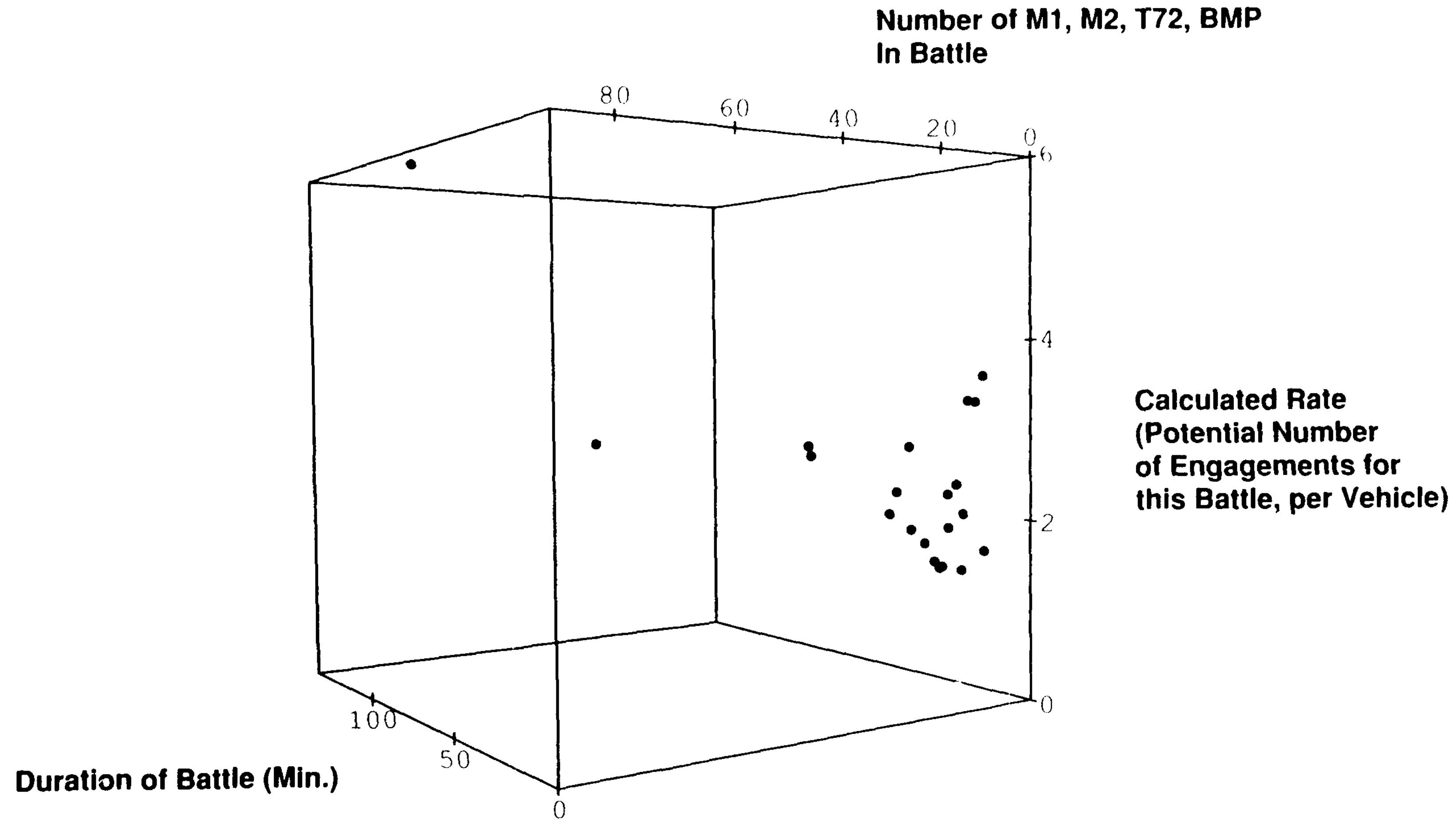


Figure 5. Potential Engagement Rate for the Battle for M1

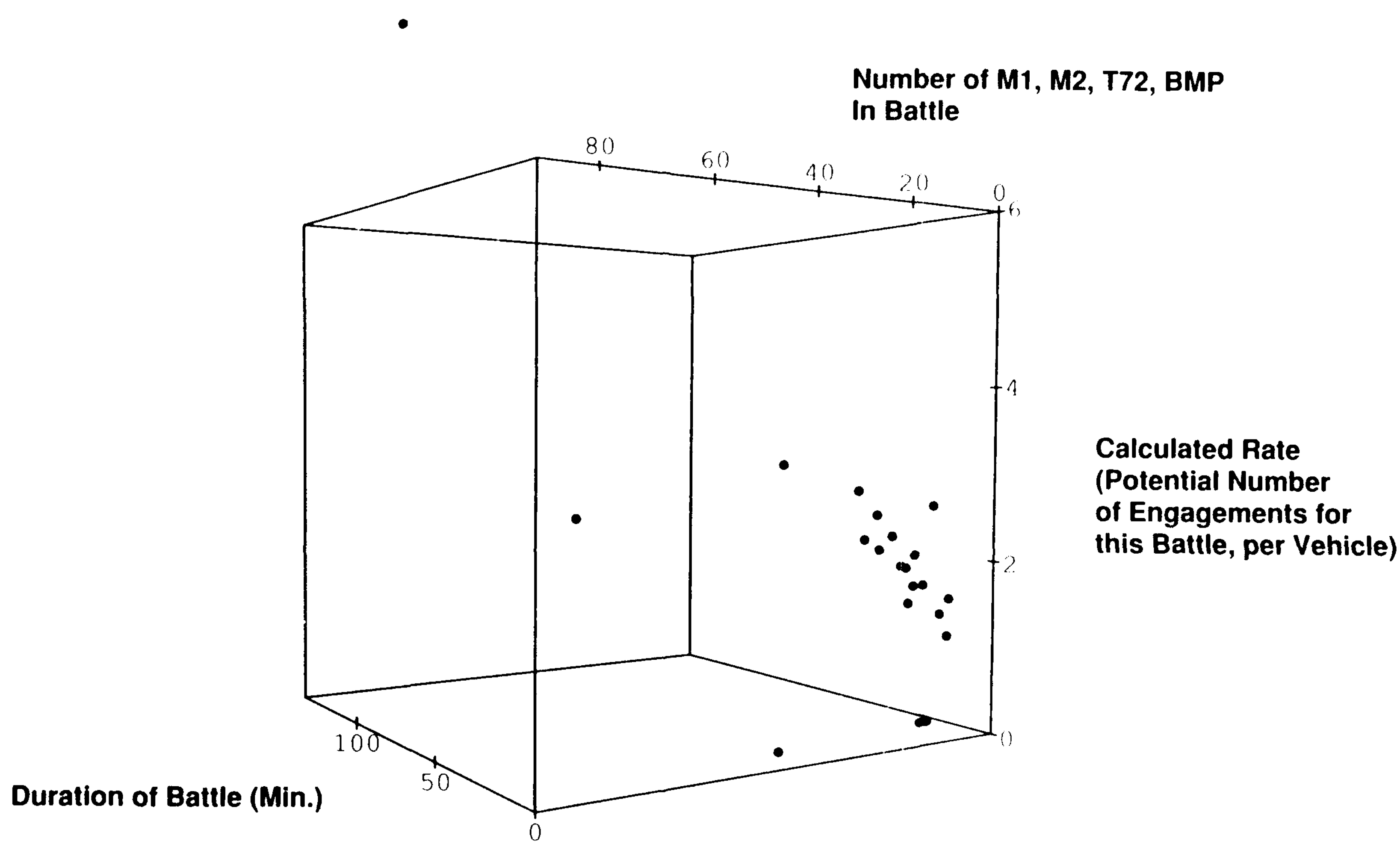


Figure 6. Potential Engagement Rate for the Battle for M2

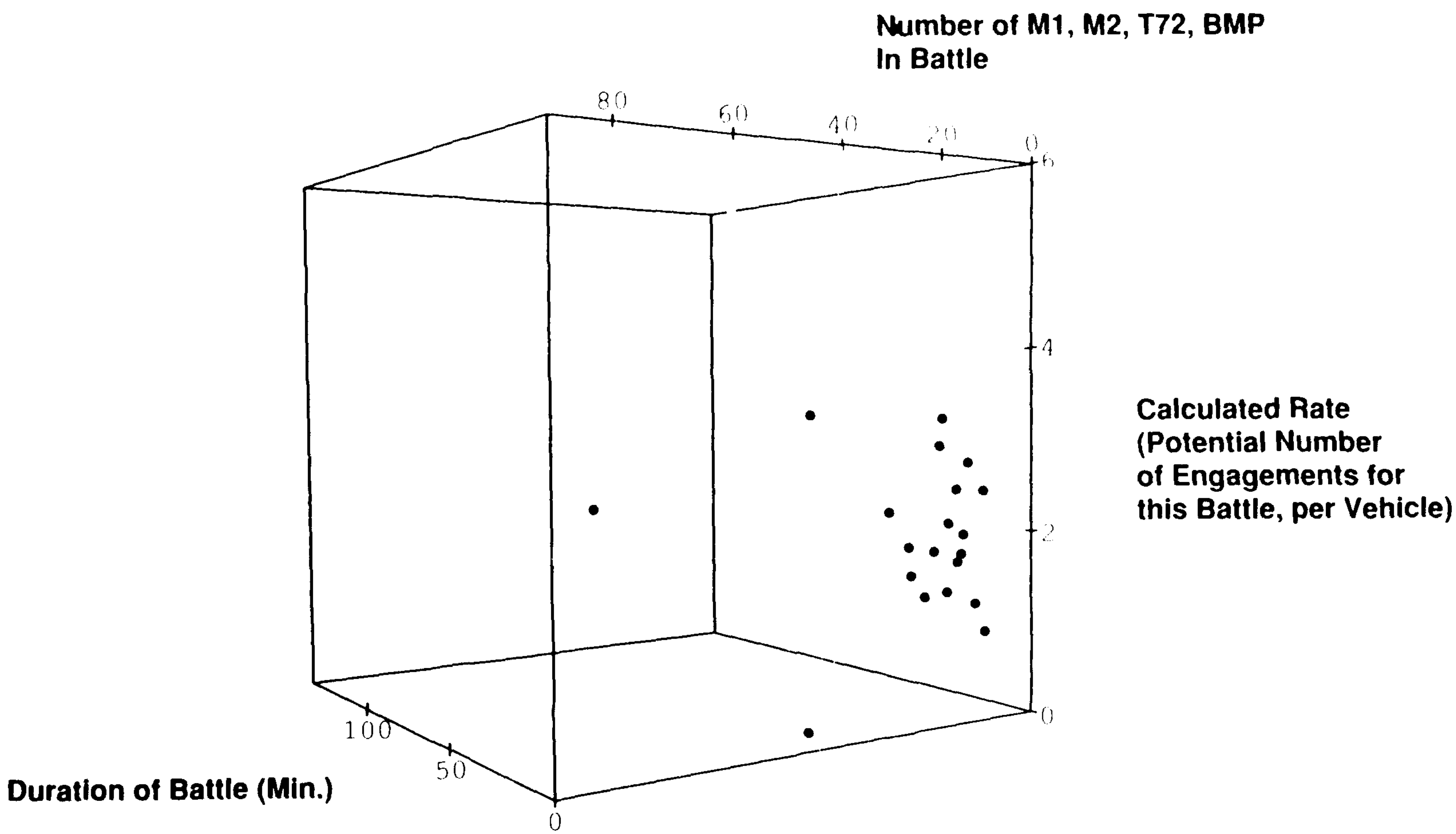


Figure 7. Potential Engagement Rate for the Battle for T72

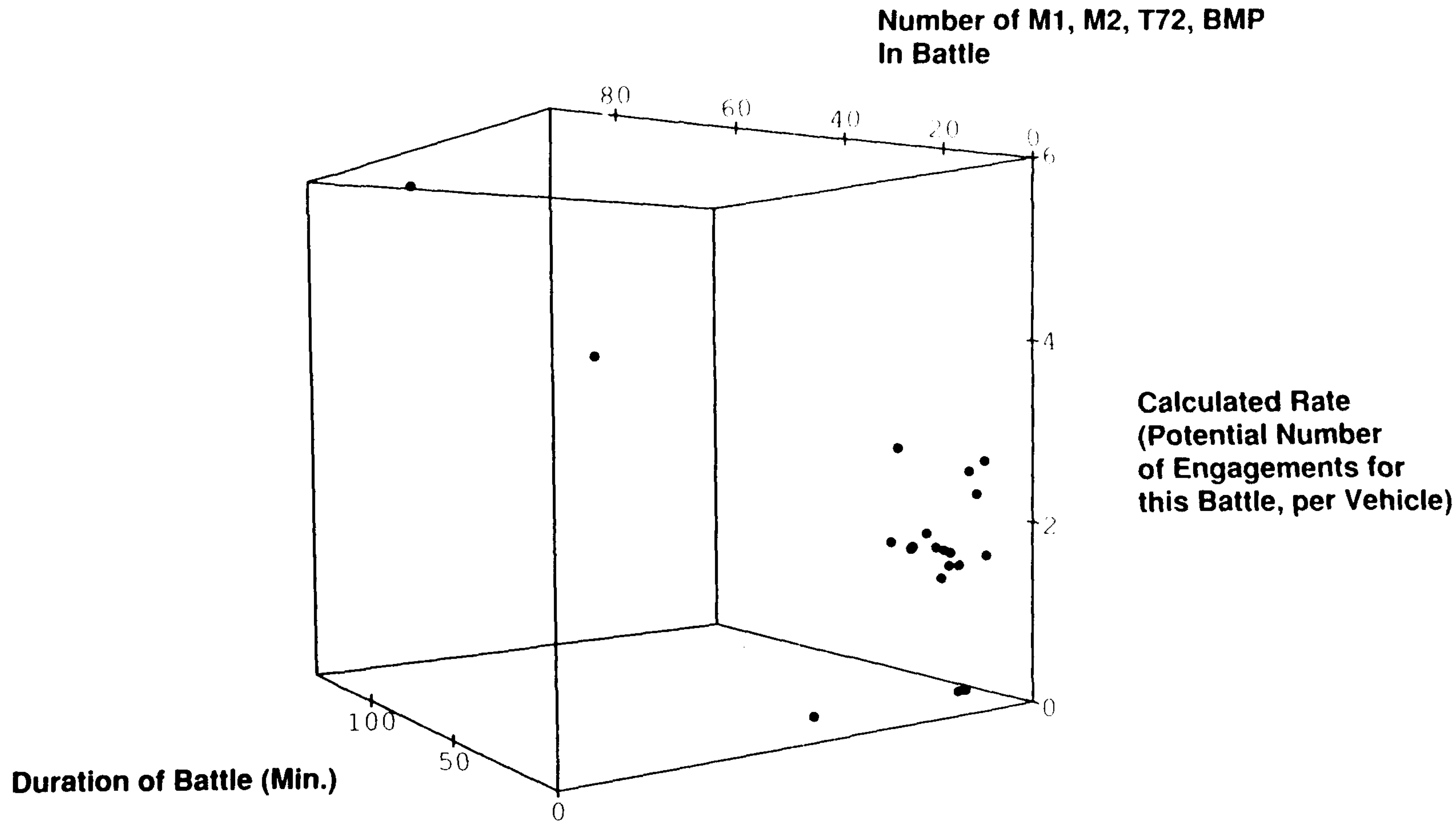


Figure 8. Potential Engagement Rate for the Battle for BMP

F. BATTLES MUST BE LOCALIZED

One assumption was that each exercise contained only one local battle. While this makes the processing less complicated, the effect of this assumption is to overstate the period of time that each vehicle is thought to be in a position to engage other targets and thereby understate the potential engagement rate. This is because the period of time value is a divisor in the engagement rate calculation.

This study sought, therefore, to develop a mechanism for processing the SIMNET exercise tapes in order to determine the spatial and temporal boundaries of each local battle. Such a method is important for several reasons beyond the calculation of engagement rates. For example, one could better understand how a large battle of long duration (e.g., a one day division-level battle) decomposes among a number of smaller battles where several may be occurring at the same time. While this decomposition will depend on several tactical factors, it nevertheless would provide information for how one could exercise TACWAR using smaller time increments and smaller terrain regions. Doing so may facilitate joining TACWAR with other models (e.g., C3EVAL) which by design have model cycles measured in minutes or hours.

To effect this method, a series of programs was developed that used the XY file mentioned above along with the ID file and the Impact file. These three files allowed the reconstruction of the path of each vehicle through time and space. In addition, each engagement instance for each vehicle could be determined.

The WAREX 5 exercise was used to demonstrate this method. The terrain for the exercise was partitioned into square regions five kilometers on a side. Since the vehicles engage at distances of one to three kilometers, this resolution should not be too small. This exercise was 52 minutes long; so two minute time intervals were established. Each record in the XY file counted as one increment in the appropriate XY-Time partition. These values formed the presence measure. Each record in the Impact file provided the XY position of the firing vehicle when it fired each munition or missile, thus providing one increment in the appropriate XY-Time partition of a second measure, the activity count.

To get a sense of what was happening on the battlefield, a time series of plots was developed using the Graphical Analysis System developed as part of the IDA Central Research Program. This system allowed the presence measure to be plotted as a time series of surfaces. The surfaces are plotted at two minute intervals over the grid of five kilometer square patches of terrain. The height of a surface is given by the count of the number of vehicles in that patch during the time interval. A vehicle that remains in one terrain patch for the two minute interval contributes 24 to presence measure count. Each surface in then colored by the activity measure. By animating the colored surfaces, or by viewing them in sequence (as in Figures 9 through 11), one observes the buildup of forces as well as the beginning and intensity of the battle nearby (but not within) the largest concentration of vehicles. In addition, starting at about minute 18, there is a small short engagement also occurring.

This method of creating measures of merit from SIMNET exercise tapes (in this case, the presence and activity levels) can be applied to many other purposes. One could also record, as separate measures, the vehicle kills, the concentrations of Blue versus Red forces, or the comparative behavior among Blue units that are at different levels of training or readiness. These display mechanisms generally may be applied to any measure that one might develop from SIMNET exercise. Moreover, these methods may be implemented using commonly available software and hardware, thus making SIMNET-based analysis available to a broader audience.

G. POTENTIAL IMPLICATIONS

Figures 1 through 4 may suggest a relationship between some measure of the intensity of the battle and the per-vehicle-minute engagement rate. This may not be surprising, if true. In short, intense battles, a vehicle may fire more often since there are more opportunities to fire. The per-battle engagement rate also may be positively related to increases in size and duration of the battle, as seen in Figures 5 through 8.

The exercises analyzed were not designed with any overall experimental control in mind, nor were several important factors taken into account towards explaining these results. For example, the battles were not differentiated by attack versus defense posture for either side. The opposing force ratios were not used. The degree of crewed versus SAFOR simulator also was not measured as a possible explanatory factor.

What this calculation demonstrated, however, was that SIMNET does appear to generate information at a useful level of detail and resolution. In the future, carefully designed series of SIMNET exercises may prove to be a robust source of data for a broad range of analyses.

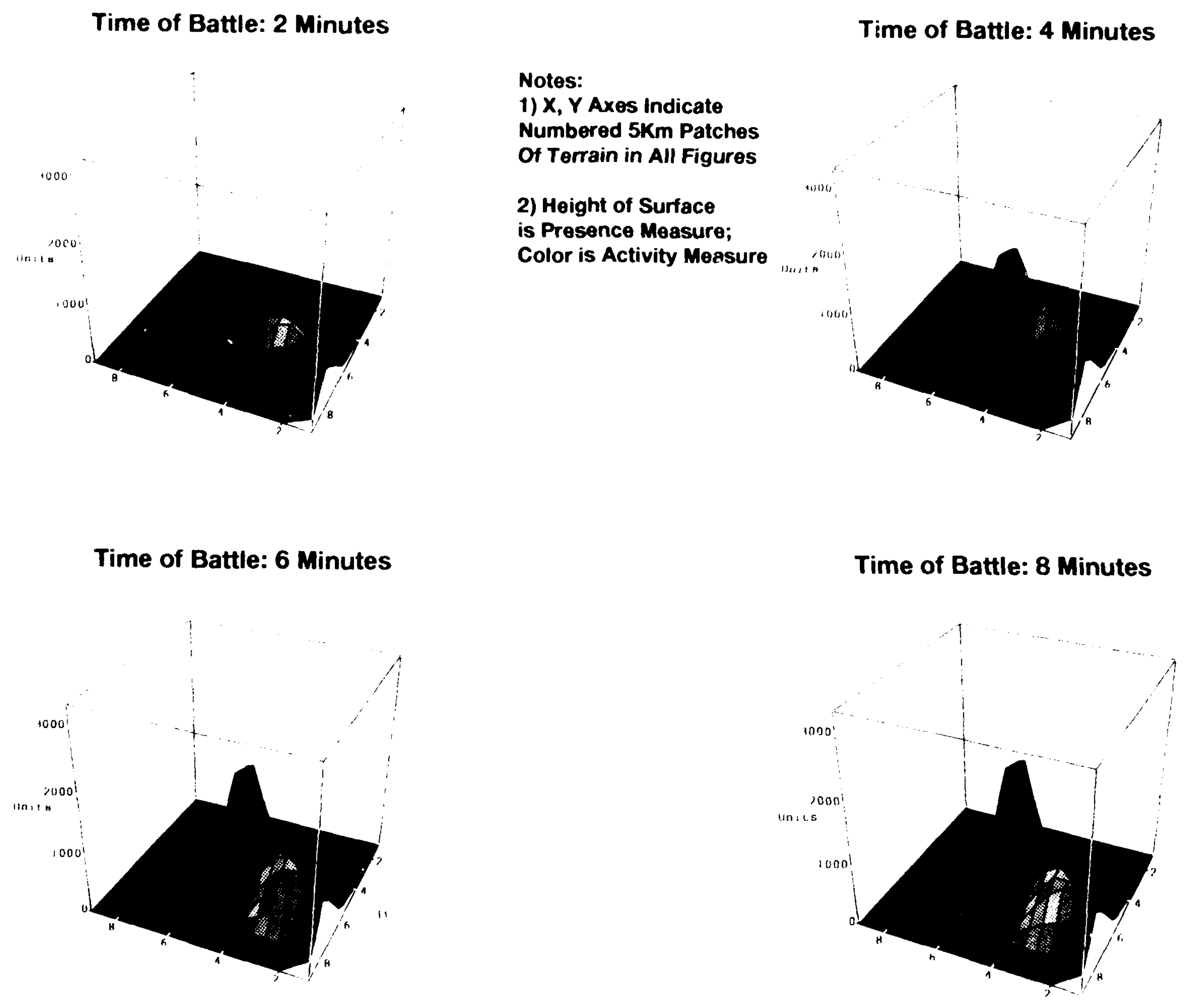
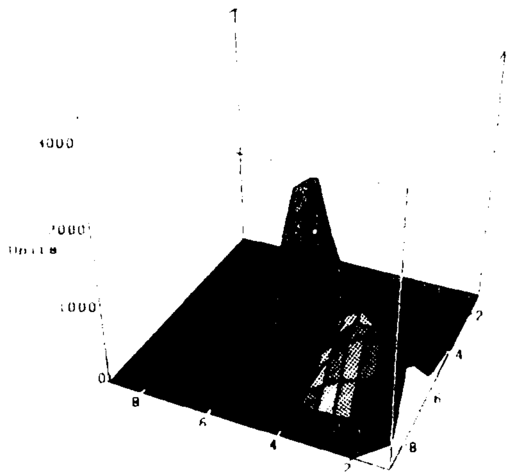


Figure 9. *Dynamic Display of Presence vs Activity*

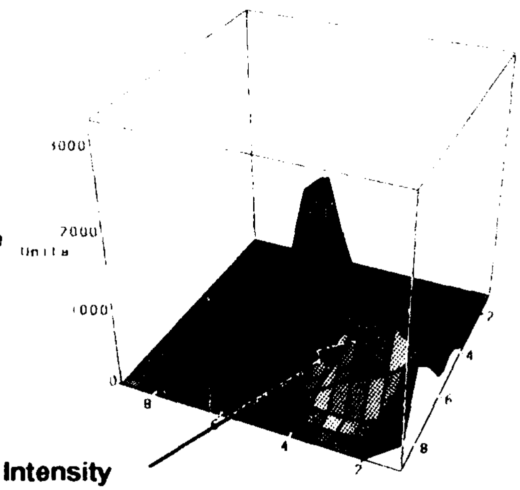
Time of Battle: 10 Minutes



Time of Battle: 12 Minutes

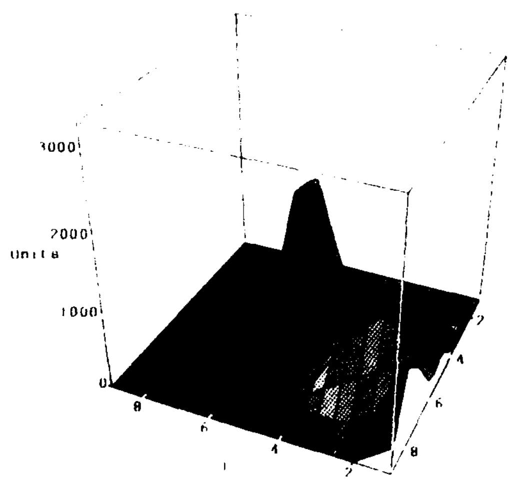
Notes:
1) X, Y Axes Indicate
Numbered 5Km Patches
Of Terrain in All Figures

2) Height of Surface
is Presence Measure;
Color is Activity Measure



Point of Greatest Intensity

Time of Battle: 14 Minutes



Time of Battle: 16 Minutes

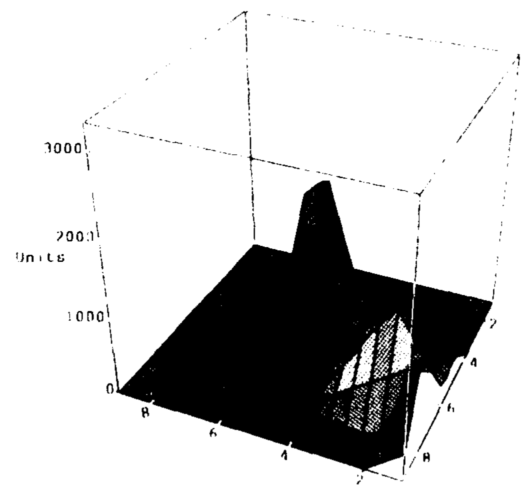


Figure 10. Dynamic Display of Presence vs Activity (continued)

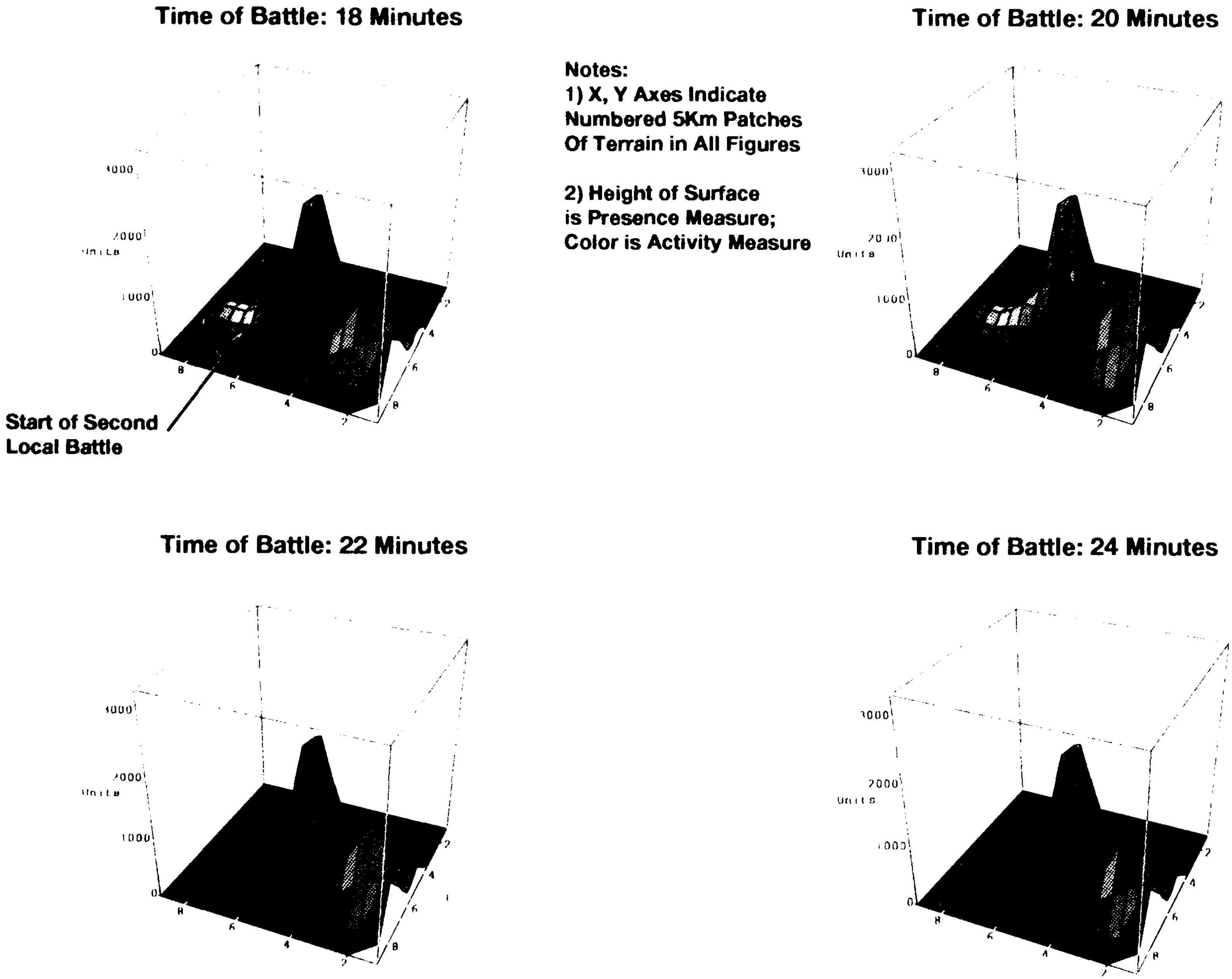


Figure 11. Dynamic Display of Presence vs Activity (concluded)

V. MISCELLANEOUS TOPICS

A. SOFTWARE AND HARDWARE REQUIREMENTS FOR WORKING WITH SIMNET OUTPUT

There are two components of the SIMNET output that are automatically recorded during each exercise. The data packets, introduced in Chapter II, are sent out by each simulator or other computer-generated vehicle and indicate the state of the vehicle at the instant the packet was generated. These data are recorded in digital form and therefore are readily subject to various standard data processing efforts. The second component is the radio net communications traffic which are recorded by Audio Recorder. These data are not in digital form and are thus more difficult to analyze; doing so involves an analyst listening to the radio traffic as it occurs on multiple frequency channels. While this latter component of SIMNET data is important, it has not been addressed by this study.

The study team received the digital SIMNET data in two forms, unprocessed and processed. Using an unprocessed data file of the exercise, one can play back the entire recorded portion of the exercise on the Stealth Vehicle and Plan View Display equipment. This set up allows very detailed after-action review, as one can position oneself anywhere on the battlefield at any instant of the battle. One also may slow down or speed up the battle in order to review it more or less carefully. But because this equipment is generally not available to the analyst, one needs to develop a means by which any analyst can readily work with the large amounts of data in each exercise.

The approach followed by this study is the analysis of the packet data, or PDUs. These packets, which are recorded on the Data Logger, contain sufficient information to describe the state of every vehicle at virtually every instant in the simulation. By examination of the PDUs, an analyst can measure many of the parameters that constitute the attrition structures of combat models. Firing rates, engagement rates, empirical hit and kill probabilities are all derivable from PDUs. One only requires a clear understanding of what is to be measured and sufficiently many replications to assure confidence in the measurements.

Difficulties with this direct approach lie largely in the amount of storage required to process the packet data. Typically, for a relatively short simulation (e.g., 20 minutes), over 100,000 blocks or sectors (512 bytes) of data are generated. This places a large demand on data handling and storage capabilities. Also, the software required to extract relevant data is not mature at this point. Various software structures have developed as the SIMNET system has evolved. In the future, new protocol standards will be developed by the ADST contractor and entirely new software may be required to extract packet data.

B. USING SIMNET TO TEST MODELING CONCEPTS

SIMNET, in its present or future forms, provides a means for examining and refining modeling concepts that exist in deterministic simulations. The wealth of data generated by SIMNET is a source of information for developing or checking the validity of fundamental algorithms and procedures that may form the core of theater-level models. These may include allocation of division assets to various battalions, such as artillery support, close air support, and resupply missions. Of particular interest to IDA analysts might be the investigation of coordinated fire techniques as they are applied in TACWAR. This application to modeling concepts is, of course, a generalization of the notion of simple parameter verification, an example of which appears in an earlier chapter of this paper.

C. REAL-TIME INTEGRATION OF SIMNET WITH TACWAR

Up to this point the focus has been on the application of SIMNET to deterministic models. An interesting reversal of roles seems possible and worth mentioning, however. In the larger exercises, such as PCC, SIMNET simulations may last hours and entail large numbers of units. Commanders are faced with many decisions and may have a number of opportunities to employ novel tactics and strategies. Were a fast-running deterministic model available to them at such junctures, these commanders might be able to take advantage of the "look ahead" features these models provide and choose tactics accordingly. For example, TACWAR might offer a set of possible outcomes based upon the current force configurations and dispositions at a commander's disposal. He or she might choose the "next move" based on TACWAR's output.

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